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Energy issues and renewables for sustainable development in Turkey

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ABSTRACT

Energy is an essential factor to achieve sustainable development. So, countries striving to this end are seeking to reassess their energy systems with a view towards planning energy programs and strategies in line with sustainable development goals and objectives. As would be expected, the rapid expansion of energy production and consumption has brought with it a wide range of environmental issues at the local, regional and global levels. Renewable energy technologies of wind, biofuels, solar thermal and photovoltaics are finally showing maturity and the ultimate promise of cost competitiveness. With respect to global environmental issues, Turkey's carbon dioxide emissions have grown along with its energy consumption. States have played a leading role in protecting the environment by reducing emissions of greenhouse gases. In this regard, renewable energy resources appear to be the one of the most efficient and effective solutions for clean and sustainable energy development in Turkey. Turkey's geographical location has several advantages for extensive use of most of these renewable energy sources.

Contents

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1. Introduction

Energy is essential to economic and social development and improved quality of life in all countries. Much of the world's energy, however, is currently produced and consumed in ways that could not be sustained if technology were to remain constant and if overall quantities were to increase substantially. The need to control atmospheric emissions of greenhouse and other gases and substances will increasingly need to be based on efficiency in energy production, transmission, distribution and consumption in the country. Electricity supply infrastructures in many developing countries such as Turkey are being rapidly expanded as policy-makers and investors around the world increasingly recognize electricity's pivotal role in improving living standards and sustaining economic growth [1–3].

There is a growing concern that long-run sustainable development may be compromised unless measures are taken to achieve balance between economic, environmental and social outcomes. Since the early 1980s, Turkish energy policy has concentrated on market liberalization in an effort to stimulate investment in response to increasing internal energy demand. Turkey's new government has continued this policy despite lower energy demand induced by the 2001 economic crisis. This paper provides an overview of energy issues and renewables for sustainable development in Turkey.

2. Global energy consumption

Global energy consumption in the last half century has rapidly increased and is expected to continue to grow over the next 50 years as shown in Fig. 1 [2]. The past increase was stimulated by relatively "cheap" fossil fuels and increased rates of industrialization in North America, Europe and Japan; yet while energy consumption in these countries continues to increase, additional factors make the picture for the next 50 years more complex [3]. These additional complicating factors include China and India's rapid increase in energy use as they represent about a third of the world's population; the expected depletion of oil resources in the near future; and the effect of human activities on global climate change [4]. On the positive side, the renewable energy technologies of wind, biofuels, solar thermal and photovoltaics are finally showing maturity and the ultimate promise of cost competitiveness [2–5].

Table 1
World primary energy demand by fuel in the Reference Scenario (Mtoe) [5].

	1980	2000	2006	2015	2030
Coal	1788	2 295	3 053	4 023	4 908
Oil	3107	3 649	4 029	4 525	5 109
Gas	1235	2 088	2 407	2 903	3 670
Nuclear	186	675	728	817	901
Hydropower	148	225	261	321	414
Biomass and waste	748	1 045	1 186	1 375	1 662
Other renewables	12	55	66	158	350
Total	7223	10 034	11 730	14 121	17 014

The total primary energy demand in the world increased from 7223 million tonnes of oil equivalent (Mtoe) in 1980 to 11 730 Mtoe in 2006 (Table 1), representing an average annual increase of 2%. However, it is important to note that the average worldwide growth from 2001 to 2006 was 4.1% with the increase from 2004 to 2008 being 4.3%. The rate of growth is rising mainly due to the very rapid growth in Pacific Asia which recorded an average increase from 2001 to 2006 of 8.6% [4].

More specifically, China increased its primary energy consumption by 35% from 2000 to 2006 [4]. Unconfirmed data show similar increases continuing in China, followed by increases in India [5]. Fuelled by high increases in China and India [4,5], worldwide energy consumption may continue to increase at rates between 3 and 5% for at least a few more years. However, such high rates of increase cannot continue for too long. Even at a 2% increase per year, the primary energy demand of 11 730 Mtoe in 2006 would double by 2050 and triple by 2070. With such high energy demand expected 50 years from now, it is important to look at all of the available strategies to fulfill the future demand, especially for electricity and transportation [4–6].

3. Major sectors for primary energy use

The major sectors using primary energy sources include electrical power, transportation, heating, industrial and others, such as cooking. The International Energy agency (IEA) data shows that the electricity demand almost dubled from 1980 to 2006 [4]. This is not unexpected as electricity is a very convenient form of energy to transport and use. Although primary energy use in all sectors has increased, their relative shares have decreased, except

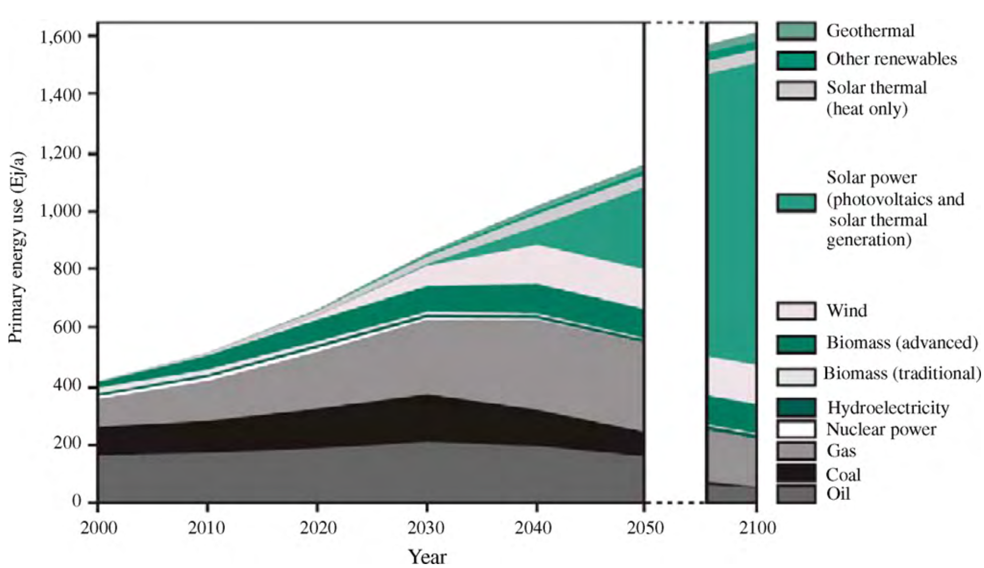

Fig. 1. World primary energy use by energy sources.

Table 2
Global energy-related CO_2 emissions (million tonnes) [4].

	OECD		Developing countries		World	
	2002	2030	2002	2030	2002	2030
Power sector	4793	6191	3354	8941	9417	16771
Industry	1723	1949	1954	3000	4076	5567
Transport	3384	4856	1245	3353	4914	8739
Residential and services	1801	1950	1068	1930	3248	4417
Other*	745	888	605	1142	1924	2720
Total	12446	15833	8226	18365	23579	38214

* Includes international marine bunkers, other transformation and non-energy use.

for transportation and electricity. The relative share of primary energy for electricity production in the world increased from about 20% in 1980 to about 30% in 2006. This is because electricity is becoming the preferred form of energy for all applications [4].

Coal is presently the largest source of electricity in the world [2–5]. Consequently, the power sector accounted for 40% of all CO_2 emissions in 2006 [6]. Emissions could be reduced by increased use of renewables. All renewables combined accounted for only 17.7% share of electricity production in the world, with hydroelectric power providing almost 90% of it. However, as the renewable energy technologies mature and become even more cost competitive in the future they will be in a position to replace a major fraction of fossil fuels for electricity generation. Therefore, substituting fossil fuels with RE for electricity generation must be an important part of any strategy of reducing CO_2 emissions into the atmosphere and combating global climate change [5,6]. Table 2 shows the energy-related CO_2 emissions.

China will add the largest capacity with its projected electrical needs accounting for about 30% of the world energy forecast. China and India combined will add about 40% of all the new capacity of the rest of the world. Therefore, what happens in these two countries will have important consequences on the worldwide energy and environmental situation. If coal provides as much as 70% of China's electricity in 2030, as forecasted by IEA [4], it will certainly increase worldwide CO_2 emissions which will further increase global warming.

At present, 95% of all energy for transportation comes from oil [3]. Therefore the available oil resources, their production rates and prices will greatly influence the future changes in transportation. Irrespective of the actual amount of oil remaining in the ground, oil production will peak soon. Therefore, the need is urgent for careful planning for an orderly transition away from oil as the primary transportation fuel. An obvious replacement for oil would be biofuels such as ethanol, methanol, biodiesel and biogases [4]. Some believe that hydrogen is another alternative, because if it could be produced economically from renewable energy sources or nuclear energy, it could provide a clean transportation alternative for the future. However, others think that electric transportation presents a more promising viable alternative to the oil-based transportation system [5].

4. World energy resources

4.1. Fossil fuels

With a view to meet the future demand of primary energy in 2050 and beyond, it is important to know the extent of available reserves of conventional energy resources including fossil fuels and uranium, and the limitations posed on them due to environmental considerations. On the other hand, if the British Petroleum (BP) estimated oil reserves are correct, world oil production may have already peaked [7]. If, however, estimates of the ultimate reserves are used, oil production may increase a little longer before it peaks. There is no question that once the world peak is reached and oil production begins to drop, either alternative fuels will have to be supplied to make up the difference between demand and supply, or the cost of fuel will increase precipitously and create an unprecedented social and economic crisis for our entire transportation system [2–5].

Coal is the largest fossil resource available to us and the most problematic from environmental concerns. From all indications, coal use will continue to grow for power production around the world because of expected increases in China, India, Australia and other countries. From an environmental point of view this would be unsustainable unless advanced "clean coal technology" (CCT) with carbon sequestration is deployed. CCT is based on an integrated gasification combined-cycle (IGCC) that converts coal to a gas that is used in a turbine to provide electricity with CO_2 and pollutant removal before the fuel is burned. However, no carbon capture and storage system is yet operating on a commercial scale. According to the estimates from the IEA [3,4], if the present shares of fossil fuels are maintained up to 2030 without any carbon sequestration, a cumulative amount of approximately 1000 gigatonnes of carbon will be released into the atmosphere [6]. This is especially troublesome in that the present total cumulative emissions of about 300 gigatonnes of carbon have already raised serious concerns about global climate change [4–6].

There are significant concerns about nuclear waste and other environmental impacts, the security of the fuel and the waste, and the possibility of their diversion for weapon production. At present, Uranium is the only fuel used for nuclear power and its terrestrial deposits are limited. Based on the known reserves of uranium, it is unlikely that nuclear power will be able to provide a significant part of our future energy. On the other hand, thorium could also be used for nuclear fission; however, to date nobody has developed a commercial nuclear power plant based on thorium. Although, these resources are potentially large, their cost-effective recovery is highly questionable [8].

4.2. Renewables

Renewables accounted for 12.89% of the world's total primary energy supply in 2006. However, almost 80% of the renewable energy supply was from biomass, and in developing countries it is mostly converted by traditional open combustion which is very inefficient. Because of its inefficient use, biomass resources presently supply only about 20% of what they could if converted by modern, more efficient, available technologies. The total share of all renewables for electricity production in 2003 was about 17.6%, a vast majority (90.3%) of it being from hydroelectric power as shown in Fig. 2 [2].

Wind technology has progressed significantly over the last two decades, driving down capital costs to as low as $900 per kW. At this level of capital costs, wind power is already economical at locations with fairly good wind resources. Therefore, the average annual growth in worldwide wind energy capacity increased from

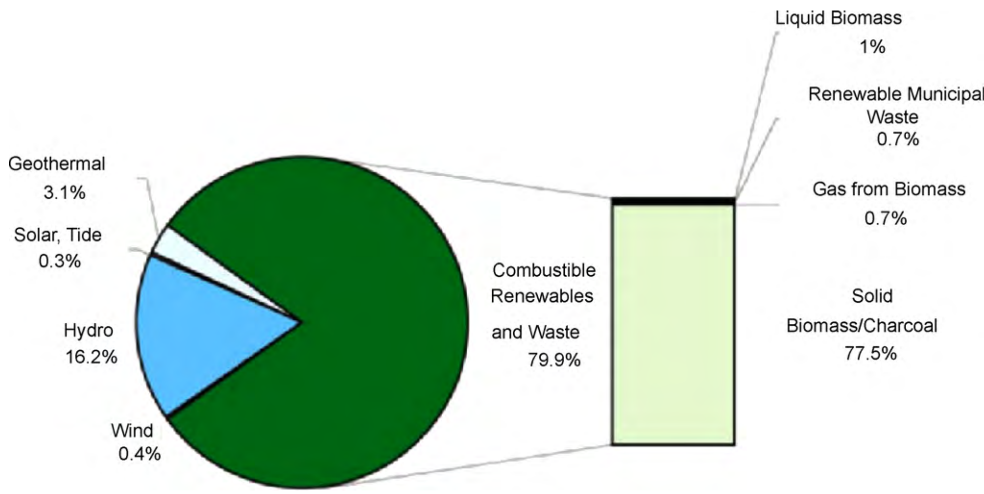

Fig. 2. Resource shares in world renewable energy supply in 2003.

8 to 94 GW for the last 10 years. The total global installed power capacity reached a level of 94 GW in 2007 [9]. The world's total theoretical potential for on-shore wind power is around 55 TW with a practical potential of at least 2 TW, which is about two-thirds of the entire present worldwide generating capacity. The off-shore wind energy potential is even larger [10,11].

The amount of sunlight striking the earth's atmosphere continuously is 1.75×10^5 TW. Considering a 60% transmittance through the atmospheric cloud cover, 1.05×10^5 TW reaches the earth's surface continuously. If the irradiance on only 1% of the earth's surface could be converted into electric energy with a 10% efficiency, it would provide a resource base of 10^5 TW, while the total global energy needs for 2050 are projected to be about 25–30 TW [6]. The present state of solar energy technologies is such that single solar cell efficiencies have reached over 20% with concentrating PV at about 40% and solar thermal systems provide efficiencies of 40–60% [12].

The worldwide growth in PV production has averaged more than 50% per year during the past 10 years. Solar thermal power using concentrating solar collectors was the first solar technology which demonstrated its grid power potential. Progress in solar thermal power stalled after that time because of poor policy and lack of R&D. However, the last 5 years have seen a resurgence of interest in this area and a number of solar thermal power plants around the world are under construction. The cost of power from these plants has the potential to go down to \$0.05/kWh with scale-up and creation of a mass market. An advantage of solar thermal power is that thermal energy can be stored efficiently and fuels such as natural gas or biogas may be used as back-up to ensure continuous operation [6].

Although theoretically harvestable biomass energy potential is of the order of 90 TW, the technical potential on a sustainable basis is of the order of 8–13 TW/year. This potential is 3–4 times the present electrical generation capacity of the world. On the other hand, the biggest advantage of biomass as an energy resource is its relatively straightforward transformation into transportation fuels. Biofuels have the potential to replace as much as 75% of the petroleum fuels in use for transportation in the USA today without the need for additional infrastructure development. Biofuels, along with other transportation options such as electric vehicles and hydrogen, will help diversify the fuel base for future transportation. Between 2000 and 2005 global ethanol production more than doubled to 36 billion litres [13,14].

Biodiesel production grew almost fourfold to 3.8 billion litres, although it started from a much smaller base. The present cost of ethanol production ranges from about 0.25 to about € 1 per gasoline equivalent litre, as compared to the wholesale price of gasoline which is between 40 and 60 € cents per liter. Biodiesel costs, on the other hand, range between 20 € cents to 65 € cents per litre of diesel equivalent. An important consideration for biofuels is that the fuel not be produced at the expense of food, while there are people going hungry in the world. This would not be of concern if biofuels were produced from agricultural and municipal solid waste (MSW).

5. Energy utilization in Turkey

Turkey is an energy importing country; more than half of the energy requirement has been supplied by imports as shown in Figs. 3 and 4. Oil, coal and gas have the biggest share in total primary energy consumption [15–17]. Turkey, with its young

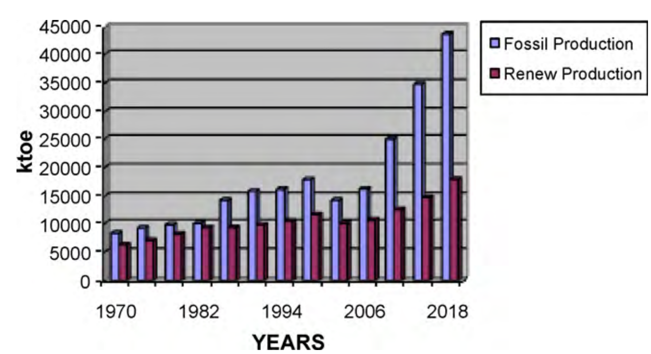

Fig. 3. Total energy production in Turkey (ktoe: thousand tonnes of oil equivalent).

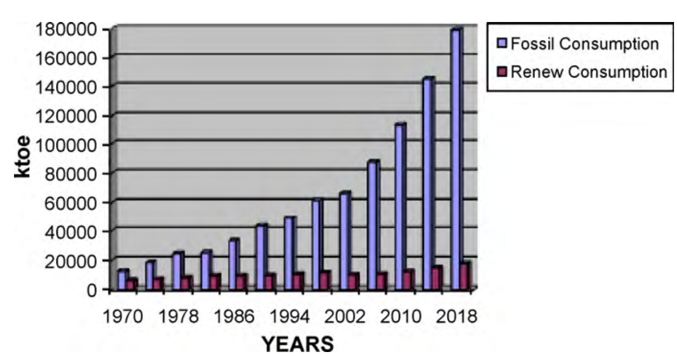

Fig. 4. Total energy consumption in Turkey (ktoe: thousand tonnes of oil equivalent).

Table 3
Total energy production in Turkey (Mtoe) [17].

Energy sources	2006	2010	2020	2030
Coal and lignite	12.90	26.15	32.36	35.13
Oil	2.28	1.13	0.49	0.17
Gas	0.84	0.17	0.14	0.10
Nuclear	–	–	7.30	14.60
Hydropower	3.86	5.34	10.00	10.00
Geothermal	0.70	0.98	1.71	3.64
Wood and biomass	5.17	5.12	4.96	4.64
Solar/wind/other	0.42	1.05	2.27	4.28
Total production	26.17	39.94	59.23	72.56

Table 4
Total energy consumption in Turkey (Mtoe) [17].

Energy sources	2006	2010	2020	2030
Coal and lignite	35.46	39.70	107.57	198.34
Oil	34.60	51.17	71.89	102.38
Gas	19.40	49.58	74.51	126.25
Nuclear	–	–	7.30	14.60
Hydropower	3.86	5.34	10.00	10.00
Geothermal	0.70	0.97	1.71	3.64
Wood and Biomass	5.17	5.12	4.96	4.64
Solar/wind/other	0.42	1.05	2.27	4.28
Total consumption	99.61	152.93	280.21	464.13

population and growing energy demand per person, its fast growing urbanization, and its economic development, has been one of the fast growing power markets of the world for the last two decades. It is expected that the demand for electric energy in Turkey will be 300 billion kWh by the year 2010 and 580 billion kWh by the year 2020. Turkey's electric energy demand is growing about 6–8% yearly due to fast economic growing [17–19].

In 2006, primary energy production and consumption has reached 26.17 and 99.61 million tonnes of oil equivalent (Mtoe) respectively (Tables 3 and 4). The most significant developments in production are observed in hydropower, geothermal, solar energy and coal production. Turkey's use of hydropower, geothermal and solar thermal energy has increased since 1990. However, the total share of renewable energy sources in total final energy consumption (TFEC) has declined, owing to the declining use of non-commercial biomass and the growing role of natural gas in the system. Turkey has recently announced that it will reopen its nuclear programme in order to respond to the growing electricity demand while avoiding increasing dependence on energy imports [15–17].

Along with the economic growth and population increase, significant increases were observed both in primary energy and electricity consumption during the 8th Plan period [18]. Consumption of primary energy reached 99.61 Mtoe as of the end of 2006 with an annual average increase of 2.9% while electricity consumption reached 169.3 billion kWh with an annual average increase of 4.6% during this period. These increases are more evident in the period following 2003, since the impact of the 2001 economic crisis was alleviated, and the economy stabilized. During this term, primary energy and electricity utilization grew at an annual average rate of 5.7% and 6.7%, respectively [18].

The TFEC in Turkey grew by 3.4% per year between 1990 and 2006. Coal and lignite are the dominant fuels, accounting for 35.6% of TEC in 2006. Oil (34.7%) and gas (15.47%) also contributed significantly (Table 4). Renewable energy, mostly biomass, waste and hydropower, accounted for 10.9%. Hydropower represented 3.8% of TFEC in 2006. Biomass, primarily fuel wood consumed by households, represented almost 5.9% [15,17]. The economic downturn in Turkey in 2000–2006 caused TFEC to decline by 6.0%. But energy demand is expected to more than double by 2010, according to Turkish government sources [15–18]. On the other hand, gas accounted for 43.8% of total electricity generation in 2006, coal 26.58% and oil at about 5%. Hydropower is the main indigenous source for electricity production and represented 20–30% of total generation from 1970 to 2006. Hydropower declined significantly relative to 2000 due to lower electricity demand and to take-or-pay contracts in the natural gas market [17–19].

6. Renewable energy in Turkey

Renewable energy supply in Turkey is dominated by hydropower and biomass [15,16], but environmental and scarcity-of-supply concerns have led to a decline in biomass use, mainly for residential heating. Total renewable energy supply declined from 1990 to 2004, due to a decrease in biomass supply [15]. As a result, the composition of renewable energy supply has changed and wind power is beginning to claim market share. As a contributor of air pollution and deforestation, the share of biomass in the renewable energy share is expected to decrease with the expansion of other renewable energy sources. Table 5 shows renewable energy production in Turkey [15–17].

Total gross hydropower potential and total energy production capacity of Turkey are nearly 50 GW and 112 TWh/year, respectively and about 30% of the total gross potential may be economically exploitable. At present, only about 35% of the total

Table 5
Renewable energy supply in Turkey [16,17].

Renewable energy sources	1990	1995	2000	2002	2006
Primary energy supply					
Hydropower (ktoe)	1 991	3 057	2 656	2 897	3 542
Geothermal, solar and wind (ktoe)	461	654	978	1 142	1 364
Biomass and waste (ktoe)	7 208	7 068	6 457	5 974	6 456
Renewable energy production (ktoe)	9 660	10 779	10 091	10 013	10 210
Share of total domestic production (%)	38	40	38	40	41
Share of TPES (%)	18	17	12	13	14
Generation					
Hydropower (GWh)	23 148	35 541	30 879	33 684	35 624
Geothermal, solar and wind (GWh)	80	86	109	153	155
Renewable energy generation (GWh)	23 228	35 627	30 988	33 837	47 639
Share of total generation (%)	40	41	25	26	26
Total final consumption					
Geothermal, solar and wind (ktoe)	392	580	910	1 048	1 148
Biomass and waste (ktoe)	7 208	7 068	6 457	5 974	5 865
Renewable total consumption (ktoe)	7 600	7 648	7 367	7 022	7 134
Share of total final consumption (%)	18	15	12	12	12

hydroelectric power potential is in operation [20]. The national development plan aims to harvest all of the hydroelectric potential by 2010. The contribution of small hydroelectric plants to total electricity generation is estimated to be 5–10% [21,22]. On the other hand, the Southeastern Anatolia Project (GAP) is one of the largest power generating, irrigation, and development projects of its kind in the world, covering 3.0 million ha of agricultural land [23]. This is over 10% of the cultivable land in Turkey; the land to be irrigated is more than half of the presently irrigated are in Turkey. The GAP project on the Euphrates and Tıgris Rivers encompasses 22 dams and 19 hydroelectric power plants. Once completed, 27 billion kWh of electricity will be generated and irrigating 1.7 million ha [23].

Among the renewable energy sources, biomass is important because its share of total energy consumption is still high in Turkey [24,25]. Since 1980, the contribution of the biomass resources in the total energy consumption dropped from 20 to 8% in 2005 [18]. Biomass in the forms of fuelwood and animal wastes is the main fuel for heating and cooking in many urban and rural areas [24,25]. The total recoverable bioenergy potential is estimated to be about 35.4 Mtoe in 2003 [24]. On the other hand, using vegetable oils as fuel alternatives has economic, environmental, and energy benefits for Turkey. Vegetable oils have heat contents approximately 90% of that of diesel fuel. The overall evaluation of the results indicated that these oils and biodiesel can be proposed as possible candidates for fuel. Organic wastes are of vital importance for the soil, but in Turkey most of these organic wastes are used as fuel through direct combustion. Animal wastes are mixed with straw to increase the calorific value, and are then dried for use [15,17,19].

Biogas systems are considered to be strong alternatives to the traditional space heating systems (stoves) in rural Turkey [15]. The economics of biogas systems are compared with traditional heating systems fuelled by wood, coal and wood mixture, and dried animal waste in three different climatic regions in the country. The technical data used in the analysis are based on the experimental results. Seven different comparisons are made between the biogas and traditional systems. The payback periods, cumulated life-cycle savings and the cost of biogas are calculated for a wide range using two unstable economic parameters, discount and inflation rates. The quality of the model and the assumptions are discussed. The results provide evidence of the economic viability of biogas systems over the traditional space heating systems of rural Turkey in many instances [16,17].

Turkey is one of the countries with significant potential in geothermal energy (at present seventh in the world) and there may exist about 2000 MW_e of geothermal energy usable for electrical power generation in high enthalpy zones. Turkey's total geothermal heating capacity is about 31 500 MW_{th}. At present, heating capacity in the country runs at 1220 MW_{th} equivalent to 147 000 households. These numbers can be heightened some sevenfold to 6880 MW_{th} equal to 585 000 households through a proven and exhaustible potential in 2010. Turkey must target 1.2 million households equivalent 7700 MW_{th} in 2020 [26–28].

The yearly average solar radiation is 3.6 kWh/m^2 day and the total yearly radiation period is approximately 2640 h, which is sufficient to provide adequate energy for solar thermal applications. In spite of this high potential, solar energy is not now widely used, except for flat-plate solar collectors. They are only used for domestic hot water production, mostly in the sunny coastal regions [28]. In 2006, country has about total 7.0 million m^2 solar collectors and it is predicted that total energy production is about 0.390 Mtoe in 2006. Although solar energy is the most important renewable energy source it has not yet become widely commercial even in nations with high solar potential such as Turkey [29]. The energy consumption for heating and cooling of buildings in Turkey was about 23 Mtoe for the year 2006 [17]. The average household in Turkey needs more that 60% of its total energy consumption for space heating. The cooling demand in buildings increased rapidly in south region of the country at the summer season. The reason, beside general climatic and architectural boundary conditions, is an increase in the internal cooling load and higher comfort requirements. These aspects show the huge potential in this field for the implementation of advanced thermal energy storage technologies in Turkey [17,29].

There are a number of cities in Turkey with relatively high wind speeds. These have been classified into six wind regions, with a low of about 3.5 m/s and a high of 5 m/s at 10 m altitude, corresponding to a theoretical power production between 1000 and 3000 kWh/(m^2 year). The most attractive sites are the Marmara Sea region, Mediterranean Coast, Agean Sea Coast, and the Anatolia inland. Turkey's first wind farm was commissioned in 1998, and has a capacity of 1.5 MW. Capacity is likely to grow rapidly, as plans have been submitted for just under a further 600 MW of independent facilities. At start 2008, total installed wind energy capacity of Turkey is only 200 MW. Electrical power resources survey and development administration (EIE) carries out wind measurements at various locations to evaluate wind energy potential over the country, and have started to compile a wing energy atlas [29].

7. Climate change in Turkey

Turkey is a rapidly growing country whose income level is moving towards that of the rest of the OECD area [15,16]. This catch-up process has been associated with a rapid growth of greenhouse gas emissions. Nonetheless, carbon emissions from any country contribute equally to the pressure on the global climate. Consequently, the major issue facing policy makers is how to contribute to reducing the burden on global resources at a low cost and without jeopardizing the rapid growth of the economy [30–34].

Economy-wide greenhouse gas emissions from fuel combustion jumped 65% in the 1990s, in contrast to the more modest growth in the rest of the OECD area. Turkey has been growing more rapidly than the rest of the OECD countries, the principal reason for the relatively rapid growth in emissions has been the very different evolution in the greenhouse gas intensity of the economy generated both by an increase in the use of energy per unit of output and an increase in GHG emissions per unit of energy supplied from renewable sources such as wood, waste, hydropower and geothermal energy [31–34].

The Turkish government is now in the process of developing a strategy to reduce the growth of greenhouse gases. This strategy will be elaborated in the context of Turkey's adhesion to the United Nations Framework Convention on Climate Change (UNFCCC). Turkey passed the national legislation to ratify the convention in January 2004. Turkey will have the obligation to implement measures and polices to mitigate greenhouse gas emissions but will not be required to meet a specific greenhouse gas emission target. Turkey will submit its first national communication to the UNFCCC by the end of 2004, including the measures that it proposes to take to limit emissions. On the other hand, the privatization of the electricity companies will also result in new pricing policies. At present, demand for electricity is boosted by a high level of what is called "non-technical" system losses. In practice, this phrase refers both to electricity that is consumed through illegal connections to the network and non-payment of bills. Overall, a significant proportion of electricity is provided without charge. The new distribution companies will need to invest in new metering systems to ensure that these practices end. The problem may be difficult to settle, in that the new distribution companies have different profiles of losses, with illegal consumption rising to 50% in some areas. Enforcing normal contract discipline, though, would further add to the de-coupling of carbon

Table 6
Turkey's air pollutant emissions by source × (1000 tonnes) [36,37].

		SO_2	(%)	NO_x	(%)	VOC	(%)	CO	(%)
Power stations	1998	1 151.2	62.8	187.3	20.3	6.4	1.2	14.9	0.3
	2005	1 285.3	66.3	182.4	16.9	7.5	1.4	23.1	0.6
Industrial combustion	1998	474.5	25.9	168.4	18.3	3.2	0.6	64.1	1.2
	2005	506.8	26.1	203.3	18.8	3.4	0.6	78.0	2.2
Non-industrial combustion	1998	94.9	5.2	191.0	20.7	196.0	35.8	1 779.2	34.4
	2005	75.5	3.9	207.4	19.2	174.5	31.5	1 461.5	40.5
Industrial processes	1998	48.7	2.7	21.9	2.4	44.1	8.1	16.4	0.3
	2005	48.6	2.5	18.2	1.7	49.0	8.8	6.7	0.2
Mobile sources	1998	62.5	3.4	341.8	37.1	88.2	16.1	2 791.0	54.0
	2005	22.2	1.1	456.0	42.2	125.7	22.7	1 473.4	40.9
Miscellaneous	1998	–	–	11.4	1.2	37.0	6.8	501.6	9.7
	2005	–	–	12.9	1.2	36.7	6.6	561.9	15.6
Total	1998	1 831.7	100.0	921.9	100.0	547.0	100.0	5 167.0	100.0
	2005	1 938.5	100.0	1 080.	100.0	554.4	100.0	3 604.0	100.0

emissions form GDP growth. In addition, both the overall price of electricity may have to rise to reduce the losses of the electricity industry and domestic and industrial tariffs will have to be re-balanced [31–33].

7.1. Emissions

7.1.1. Conventional pollutants

Turkey has achieved de-coupling of SO_x, NO_x and CO emissions from economic growth. In 2005, estimated SO_2 emissions are 1.9 million tonnes, increased by 6% between 1998 and 2005, while GDP and fuel consumption increased by 26 and 23% respectively. SO_x emission intensity (per unit of GDP) fell by 16% between 1998 and 2005. However, SO_x emission intensity is still over 3 times higher than the OECD average. Major contributors to SO_x emissions continue to be power plants (66.3%) and industrial combustion (26.1%) [34–37].

NO_x emissions, estimated at 1.1 million tonnes in 2005, had increased by 17% since 1998 [34]. NO_x emission intensity (per unit of GDP) decreased between 1998 and 2005 from 2.1 to 1.9 kg/USD 1000. However, NO_x emission intensity still exceeded the OECD average by more than 50%. The major contributor to NO_x emissions continued to be mobile sources. Their share in total emissions increased by 5% compared with 1998. Power stations and industrial combustion accounted for 16.9 and 18.8% respectively (Table 6) [34–37].

Carbon monoxide emissions amounted to 3.6 million tonnes in 2005, a 30% decrease since 1998 and mostly come from non-industrial (41%) and mobile (41%) sources (Table 7). Since 1998, the contribution from non-industrial fixed sources has increased while that from mobile sources has decreased by 13%. On the other hand, volatile organic compound (VOC) emissions have increased slightly. Total emissions were estimated at 554 400 tonnes in 2004, with non-industrial fixed sources contributing 31.5%, mobile sources 22.7% and solvents 28.4% of total VOC emissions [34–37].

Table 7
Greenhouse gas emissions by gas (million tonnes CO_2 eq.) [36,37].

Years	CO_2	CH_4	N_2O	F gases	Total
1990	139.6	29.2	1.3	0.0	170.1
1992	152.9	36.7	4.0	0.0	193.6
1994	159.1	39.2	2.2	0.0	200.5
1996	190.7	45.0	6.1	0.4	242.1
1998	202.7	47.7	5.6	0.7	256.6
2000	223.8	49.3	5.8	1.1	280.0
2002	216.4	46.9	5.4	1.9	270.6
2003	231.0	47.8	5.3	2.3	286.3
2004	241.9	46.3	5.5	2.9	296.6
2005	256.3	49.4	3.4	3.2	312.4

7.1.2. Greenhouse gases

Between 1990 and 2005 total greenhouse gas (GHG) emissions increased by 84% from 170 Tg/CO_2eq in 1990 to 312.4 Tg/CO_2eq in 2005 (Table 7), in line with GDP growth [15]. The energy sector accounted for 77.3% of the total in 2005. The other contributing sectors are the waste sector (9.5%), industrial processes (8.1%) and agriculture (5.1%) [34]. On the other hand, CO_2 emissions account for 82.1% and CH_4 emissions for 15.8% of total GHG emissions. Most (92%) of total CO_2 emissions are from fossil fuel combustion. The energy sector was responsible for the highest emission increase. The replacement of lignite and coal by oil and natural gas in energy supply resulted in stabilizing emission trends after 1998 [34].

7.2. Air quality

7.2.1. Air quality trends

Trends in reducing annual average concentrations of SO_2 and particulate matter (PM) in cities showed overall progress between 2002 and 2008. In cities such as Ankara, Gaziantep, Izmit, Samsun, Sivas and Diyarbakir pollutant concentrations decreased, particularly during winter seasons, in some cities from levels over 260 $\mu g/m^3$. This progress reflects major changes in energy supply for domestic heating, with (i) natural gas substituting for coal in a number of cities and (ii) prohibition of the use of high-sulphur coal in 2005 [36].

However, in cities where industry has continued to expand, SO_2 and PM concentrations have not decreased. Average winter concentrations have exceeded TLV, and average concentrations of SO_2 and PM_{10} have remained above the WHO guideline of, respectively, 20 and 50 $\mu g/m^3$. For example, in Denizli, Kütahya, Karabük and Van, the PM_{10} concentrations reached over 130 $\mu g/m^3$ in 2007; in Kayseri, PM concentrations in the 2007/2008 winter season reached 125 $\mu g/m^3$ and SO_2 concentrations 58 $\mu g/m^3$ [36,37].

7.2.2. Air quality monitoring

Only SO_2 and PM concentrations in ambient air have been monitored on a regular basis across the country. In certain cities other pollutants have also been monitored: in Istanbul NO_x, CO, O_3 and HC are monitored by the municipality. A draft 2006 Regulation on Air Quality Evaluation and Management aimed to expand air quality monitoring to include 13 additional pollutants on a regular basis, in line with Turkey's commitment to transpose the EU Air Quality Framework Directive and its sister Directives [34,35].

Historically, air pollution monitoring in urban areas has been performed by the Ministry of Health. Recently responsibilities have shifted to the Ministry of Environment and Forestry (MEF) and the monitoring network has expanded, benefiting from the efforts of provincial environmental departments and of universities. In 2006,

200 semi-automatic measurement stations monitored SO_2 and PM concentrations in 80 provinces. Today, all the provinces have at least one automatic measurement station for SO_2 and PM_{10}, part of the national Air Quality Monitoring Network. In addition, mobile air quality monitoring vehicles have been introduced. A national reference laboratory (under MEF coordination) is in the process of accreditation with support from the Marmara Research Center.

7.3. Regulatory instruments

7.3.1. Emissions from stationary sources

The regulatory framework for managing emissions from stationary sources has improved during the review period. The 2005 Regulation on Control of Air Pollution Resulting from heating introduced new emission standards for burning facilities and required emission certificates before facility operations could begin. It also prohibited the marketing and use of coal not in compliance with quality standards. This regulation contributed to switching from coal to natural gas for heating purposes. Coal consumption in Istanbul was expected to be 1.5–2.0 million tonnes in the winter of 2007–2008, down from 8 to 10 million tonnes in earlier years.

Installations emitting air pollutants continue to be subject to two categories of permitting procedures, with a distinction between large installations. However, emissions from waste incinerators and co-incinerators are regulated mainly by waste legislation. The creation of a Turkish IPPC Centre is envisaged with information, or both information and executive, responsibilities for integrated permitting matters. The introduction of these new permitting procedures would parallel the introduction of new limit values and standards required by the transposition of EU legislation [35]. On the other hand, the 2007 amendments to the 1983 Law on Environment introduced provisions for tougher penalties for non-compliance with permitting procedures. For example, an administrative fine of TRY 24 000 was introduced for: operation of installations without a permit; continuing operation in spite of permit cancellation; performing changes on a facility without prior approval by competent authorities; not carrying out changes requested by authorities as a result of inspections [34].

7.3.2. Emissions from mobile sources

During the review period, regulations for emissions from motor vehicles have been substantially revised, with EU requirements providing important benchmarks. For example, Euro III level standards, which had been applied to vehicles manufactured in the EU, became applicable in Turkey in 2003 [35]. On the other hand, the Euro IV level standard has been applied since January 2008 for new vehicles and will be applicable in 2009 for vehicles registered before 2008. Compliance is evaluated and certified through bi- or tri-annual inspections that have to be conducted at authorised stations under the 2005 Regulation on Opening and Operating of Vehicle Examination Stations and on Vehicle Examinations. The 2003 Regulation on Informing Consumers on Fuel Economy and CO_2 Emissions of New Passenger Cars entered into force on 1 January 2009 [17,35].

Regulations on fuel quality have also been revised, in line with the EU Quality of Petrol and Diesel Fuels Directive. The use of leaded gasoline was totally banned in 2004. The Ministry of Industry and Trade employs 620 inspectors, 600 of whom work in Provincial Directorates located in 81 cities and perform market surveillance activities. In 2007, the sulphur content of diesel oil was restricted to 50 mg/kg, which is 80 times lower than before. There are plans to further restrict the levels to 10 mg/kg in 2009. Sulphur content standards for unleaded gasoline are lowered to the same levels, in line with the Directive regulating the sulphur content of liquid fuels. The date of the full transposition remains set for 2010 [34].

7.4. Economic instruments

Currently, no environmental charges or taxes for managing air pollution are applied directly. Previous funding arrangements, with part of the revenue from motor vehicle inspection fees, vehicle sales and fees on airplane tickets going to the Environmental Pollution Prevention Fund, were discontinued with the Fund's elimination in 2001.

7.4.1. Environmentally related taxes

Environmentally related taxes include taxes on fuels and on vehicles. Road fuel prices in Turkey are among the highest in OECD countries. A special consumption tax on gasoline and diesel fuels was introduced in 2002 and its increase over the last 5 years is associated with a decrease in the use of motor fuels per unit of GDP. Given that many low-income households in Turkey do not own a car, this reform has touched middle-income and higher income households. Since the tax rate for diesel fuel with sulphur content below 0.05% (1.0 Turkish liras/litre) is higher than for fuel with a higher sulphur content (between 0.05 and 0.20%), the wrong incentive is given from an environmental perspective [33,34].

The annual tax on motor vehicles also has environmental ramifications. Its rates increase with cylinder volume. As vehicles with larger cylinder volumes emit more pollutants, this provides incentives to purchase smaller vehicles. However, the tax decreases with the vehicle's age, which is inconsistent with pollution reduction objectives. The replacement of older vehicles in the fleet has been encouraged by separate economic incentives. On the other hand, preferential tax rates apply to other fuels, such as LPG and biodiesel. For example, the LPG tax rate is EUR 0.30/l compared to EUR 0.78/l for low-octane unleaded gasoline. This differentiation provides incentives to use LPG. When gasoline or diesel is mixed with biofuels (ethanol and biodiesel) manufactured from domestic agricultural products, a lower tax rate is applied according to the mixing ratio.

7.4.2. Energy prices

Retail electricity prices are relatively high in Turkey, at approximately USD 0.163/kWh for households and USD 0.1/kWh for industrial consumers. Turkey currently has implicit cross-subsidies between regions and for certain subcategories of consumers. The government is considering a transition period, with a tariff equalisation method, to reduce cross-subsidies and progressively introduce cost-effective tariffs in the medium term. Differences in energy prices are mainly due to tax differentiation by fuel types: the special consumption tax on natural gas is much lower than on fuel oils. However, no special consumption tax is applied to coal.

8. Integration of air quality concerns into energy policy

The basic principle of Turkish energy policy, as set out in the 9th National Development Plan (2007–2013), was to ensure sufficient energy supply to meet the increasing demand, at the lowest cost possible. The 9th plan also introduced provisions for minimising negative environmental impacts, improving energy efficiency and increasing the share of renewable energy in energy consumption [19].

8.1. Reducing pollution from energy production

The government further reformed the regulatory framework to reduce pollution from energy production. In 2006, the new Regulation on Control of Air Pollution from Industrial Plants set standards for emissions of NO_x, SO_2, CO and PM from combustion plants. PM and CO standards were lowered for both solid and liquid fuel-fired power plants. PM standards were tightened from 150 to 100 mg/m^3 for solid fuel-fired power plants and CO standards were

lowered from 250 to 200 mg/m^3 (for solid fuel-fired plants) and from 175 to 150 mg/m^3 (for liquid fuel-fired plants) [16,31].

Some investments have already been made, especially to address the environmental impacts of the high-sulphur content of domestic lignite. New lignite-fired power plants have been equipped with flue gas desulphurisation (FGD) technology to comply with regulations. Six of eleven pre-1986 lignite-fired plants have been retrofitted with electrostatic precipitators (ESP) to reduce particulate emissions. However, not all electrostatic precipitators are working at maximum efficiency. Construction of one power plant based on circulating fluidised bed technology has recently been completed [16,32,35]. This first application of advanced coal technology in Turkey, designed to use low-quality lignite with high-sulphur content, was followed by other plants. Studies on compliance with the EU LCP Directive indicate that an investment of over USD 1 billion would be needed to retrofit installed FGD and ESP facilities and to adopt advanced coal technologies [15,35].

8.2. Improving energy efficiency

Energy intensity decreased by 8% between 1990 and 2005 and is below the OECD average. Its improvement through improved sectoral energy efficiencies is an important objective of Turkey, which should bring multiple benefits: economic benefits, environmental benefits and related health benefits. Official studies have demonstrated that Turkey has large energy conservation potential (25–30%). Energy efficiency policies have been implemented in the industrial, residential and services sectors. General investment support programmes also have an indirect positive impact on energy efficiency. There are no direct tax incentives to encourage end-use energy efficiency, nor is there any other kind of direct financial incentives. On the other hand, the National Energy Conservation Centre (EIE/NECC) has provided training to consumers on energy conservation measures, conducted energy audits in industry, maintained energy consumption statistics for the industrial sector and public buildings, and co-ordinated dialogue and co-operation with the relevant institutions. In 2004, the Energy Efficiency Strategy was adopted to support, in a more comprehensive way, energy efficiency in the final energy consumption sectors and more actively engage ministries and stakeholders in applying energy efficiency measures [34].

8.3. Promoting renewable energy

In Turkey, renewables represent about 12% of TPES. More than half of the renewables used in Turkey are combustible fuels and waste, the rest being mainly hydro, solar and geothermal. Turkey is richly endowed with hydropower, wind and geothermal resources. Sectoral studies have indicated that small-scale hydropower (less than 20 MW) is underdeveloped, with 90 plants in operation compared with 350 prospective development sites and a total potential production of 33 TWh of electricity per year (about 25% of current demand). It is estimated that Turkey has the potential for up to 11 000 MW of wind power capacity (mostly along the coasts), capable of generating about 25 TWh of electricity per year [16,28,32,38,39].

There is also large potential for geothermal and solar thermal applications in Turkey. Solar collectors are already a significant, market-driven business. The government expects the use of geothermal and solar energy to double between 2007 and 2020. The Geothermal Energy Law, enacted in 2007, aims to boost geothermal residential heating. The organic component of waste incineration is also considered a renewable option in the future, using appropriate technology to meet high health and environmental standards. On the other hand, commercial use of renewable energy has not developed rapidly. Financial assistance is being provided for the development of renewable energy projects. In 2004, USD 200 million was made available; by 2008, about half had already been committed to finance 19 projects with several other projects under preparation [19,34,40].

9. Conclusions

Energy access for all will require making available basic and affordable energy services using a range of energy resources and innovative conversion technologies while minimizing GHG emissions, adverse effects on human health, and other local and regional environmental impacts in the country. To accomplish this would require governments, the global energy industry and society as a whole to collaborate on an unprecedented scale. The method used to achieve optimum integration of energy sustainability with more efficient energy systems should be made. Renewable energy supply in Turkey is dominated by hydropower and biomass, but environmental and scarcity-of-supply concerns have led to a decline in biomass use, mainly for residential heating. As a contributor of air pollution and deforestation, the share of biomass in the renewable energy share is expected to decrease with the expansion of other renewable energy sources such as solar and wind. Turkey has substantial renewable energy sources such as hydropower, solar, biomass and wind power. There is also significant potential for wind power development. Renewables exception of large hydro are widely dispersed compared with fossil fuels, which are concentrated at individual locations and require distribution. Hence, renewable energy must either be used in a distributed manner or concentrated to meet the higher energy demands of cities and industries.

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